[Supplementary material]

Settlement and social organisation in the late fourth-millennium BC in Central Europe: the waterlogged site of Zurich-Parkhaus Opéra

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Methods

Pile field analysis and dendrochronology

All piles were sampled. For a thorough pile field analysis, a number of metadata need to be collected in order to assist the selection of samples to be measured and to gain the most information from as few resources as possible. These metadata are:

1. Individual sample number
2. Species
3. Shape (round, different forms of splitting and further special forms)
4. Size
5. Number of rings
6. Presence of pith
7. Presence of sapwood
8. Presence of waney edge
9. Exact coordinates (sometimes even two sets of coordinates, if posts are heavily tilted)
10. Dendrochronological potential
11. Notes (unusual anatomy etc.)

It is necessary to use codes instead of text for use in a database.
Experience shows that one person who is trained in wood anatomy can manage about 120 samples a day gathering all these information in a field lab during excavation. This has also the advantage, that the excavation's director has constant dendrochronological expertise and advice on site commenting on selection, cutting and storage of samples. The resulting database was used to carry out GIS mapping.

Maps of species, pile density and all other possible combinations of features were the first results of the pilefield analysis, revealing palisades or rows of piles with uniform properties. For instance a palisade consisting of split alder stems and dense lines of thinner round poplars were encountered, but also lines of split oaks (Figure 4). Such non-random pile structures were defined as building structures and these were also managed in the same database (Figure S3). For each pile, the information whether it belonged to a certain building structure was noted, thereby preventing double assignments.

Frequently, rectangular arrangements of split oak stems set at regular intervals were identified. If dendrochronologically dated piles were attributed to a building structure, we first formed the hypothesis, that the given building belongs to this very phase and tested the hypothesis by dating more piles of the same structure. If the date was repeated, the hypothesis was accepted. If cutting dates from other phases were found then the building was rejected. If undated piles fill the gaps in regular settings of dated piles it has proven legitimate to attribute them to the same phase. It is not acceptable to attribute them to the same cutting date, since there is ample evidence of reused timber and repair dates.

Building structures that could not be dated dendrochronologically were tested for evident spatial relations to dated structures. If they ran across dated structures of certain phases then we took this as indication that they could not have belonged to the same phase. Thus, we reduced the number of possible phases they could belong to. When this approach did not lead to clear attributions of hitherto undated building structures to phases, then we resorted to radiocarbon dating. Following this series of steps, we were able to date most building structures.

Regular arrangements of piles can be seen as a special case of archaeological context. Such context information can be used to aid the dating of tree ring sequences that would be too short for independent dendrochronological dating. Short ring series are problematic in dendrochronology, since the probability of false matches rises with the number of comparisons and with decreasing overlap of the compared series. For instance, a random series of 30 rings compared to 8000 possible synchronous positions of any given reference is more likely to show a random match than a 60-ring series compared to 500 possible positions. It is therefore common in dendrochronology to use context information although it is rarely communicated. For instance, beams from medieval roof frames are normally not compared to Neolithic tree ring series, although the theoretical possibility exists, that medieval builders used subfossil trunks from the Neolithic. In the pile field analysis of Parkhaus Opéra the context was used for dating, e.g. by forming explicit hypotheses. Such a

hypothesis might read like "pile X with 30 rings is the same date as dated pile Y+/-5 years". Thus, the similarity of the growth curves was only compared for ten positions of assumed synchronicity in order to keep the probability of mistakes low.

The dendrochronological analyses followed a dendro-typological approach. This approach is best applied to larger series of samples and involves the sorting of dendrodata into so-called dendrogroups according to species, series length, growth trend, cross-sections and anatomical anomalies (Billamboz 2008: 147; Bleicher & Burger 2015). For illustration, several dendrogroups of the first settlement phase are given in Figure 5. This method aids the dating process specifically of shorter series and provides a basis for further ecological and economic analyses, which are not the focus of this paper. Overall, more than 2800 samples were analysed dendrochronologically, 2384 of which were organised into dendrogroups and 2121 samples could be dendrodated.

The cutting dates were mapped together with the building structures in order to identify the actual building dates and separate them from isolated older dates within a building that indicates reused timber (Figure S4). Cutting dates after the initial construction are interpreted as relating to repair works. Phases were defined as beginning of construction until end of repairs. These phases were then compared with the dendrochronological results from stratified horizontal timbers from the layers, which allowed us to link dendrochronological phases with stratigraphical layers (Figure 2; Figure S5). This approach allowed to double-check the results and their consistency by comparison of the spatial relationships between the dendrochronologically and therefore independently defined buildings on the one hand and the loam patches from the layers on the other hand for each phase and stratigraphical layer.

References

BILLAMBOZ, A. 2008. Dealing with heteroconnections and short tree-ring series at different levels of dating in the dendrochronology of the Southwest German pile-dwellings. *Dendrochronologia* 26: 145–55. https://doi.org/10.1016/j.dendro.2008.07.001

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Table S1. Sizes of individual buildings in the different phases.

Building #	Mayes. Length [m]	Full length documented	Width [m]	Full width documented	Area [sqm]	Full area documented	Phase
101	5.32		3.2	YES	14.94		1
102	10.39	YES	3.16	YES	32.69	YES	1
103	7.95	YES	3.47	YES	25.97	YES	1
104	9.95	YES	3.58	YES	35.49	YES	1
106	11.95	YES	3.77	YES	44.96	YES	1
108	12.04	YES	3.8	YES	45.54	YES	1
109	7.31	YES	3.46	YES	25.64	YES	1
110	12.03		2.89	YES	36.18		1
111	11.17	YES	3.79	YES	41.62	YES	1
112	13.85	YES	3.91	YES	53.91	YES	1
113	14.83	YES	4.19	YES	62.56	YES	1
151	6.16	YES	3.16	YES	19.23	YES	1
152	14.24	YES	3.44	YES	48.53	YES	1
171	7.9		4.26	YES	33.34		1
172	6.86	YES	3.31	YES	22.28	YES	1
301	17.61		3.27		28.46		3
302	14.68	YES	4.42	YES	64.18	YES	3
303	7.47		4.11	YES	26.35		3
304	8.56		2.45		10.49		3
305	18.52	YES	4.73	YES	87.09	YES	3
306	12.63		3.97	YES	48.39		3
307	9.4		3.36	YES	20.43		3
308	16.52	YES	4.58	YES	73.87	YES	3
309	9.13	YES	3.09	YES	27.47	YES	3
310	9.49		3.26	YES	28.67		3
311	6.01		3.25	YES	17.48		3
312	14.06	YES	4.21	YES	57.5	YES	3
313	12.06	YES	3.79	YES	40.23		3
314	13.8		4.7	YES	58.66		3

315	12.38		4.15	YES	45.01		3
316	13.75		3.99	YES	43.04		3
317	11.29	YES	3.61	YES	39.97	YES	3
318	14.62	YES	3.9	YES	54.1	YES	3
319	16.05		3.98	YES	55.68		3
320	15.08		3.46	YES	46.75		3
321	12.09		3.82	YES	39.57		3
322	10.51		3.84	YES	38.76		3
323	7.58		4.06	YES	23.3		3
324	10.08	YES	3.75	YES	37.79	YES	3
325	6.59	YES	3.53	YES	23.27	YES	3
326	11.34		3.94	YES	42.67		3
327	8.15		3.42	YES	27.54		3
404	9	YES	3.1	YES	27.9	YES	4
405	8		3.8	YES	30.4		4
407	7.5		3.5	YES	26.25		4
408	9.5	YES	3.6	YES	34.2	YES	4
601	7.8		2.5	YES	19.5		6
602	12	YES	3.8	YES	45.6	YES	6
603	11.3	YES	3.6	YES	40.68	YES	6
604	11	YES	3.2	YES	35.2	YES	6
605	10.7	YES	3.7	YES	39.59	YES	6

Figure S1. Map of raw materials used for grinding tools in layer 13.

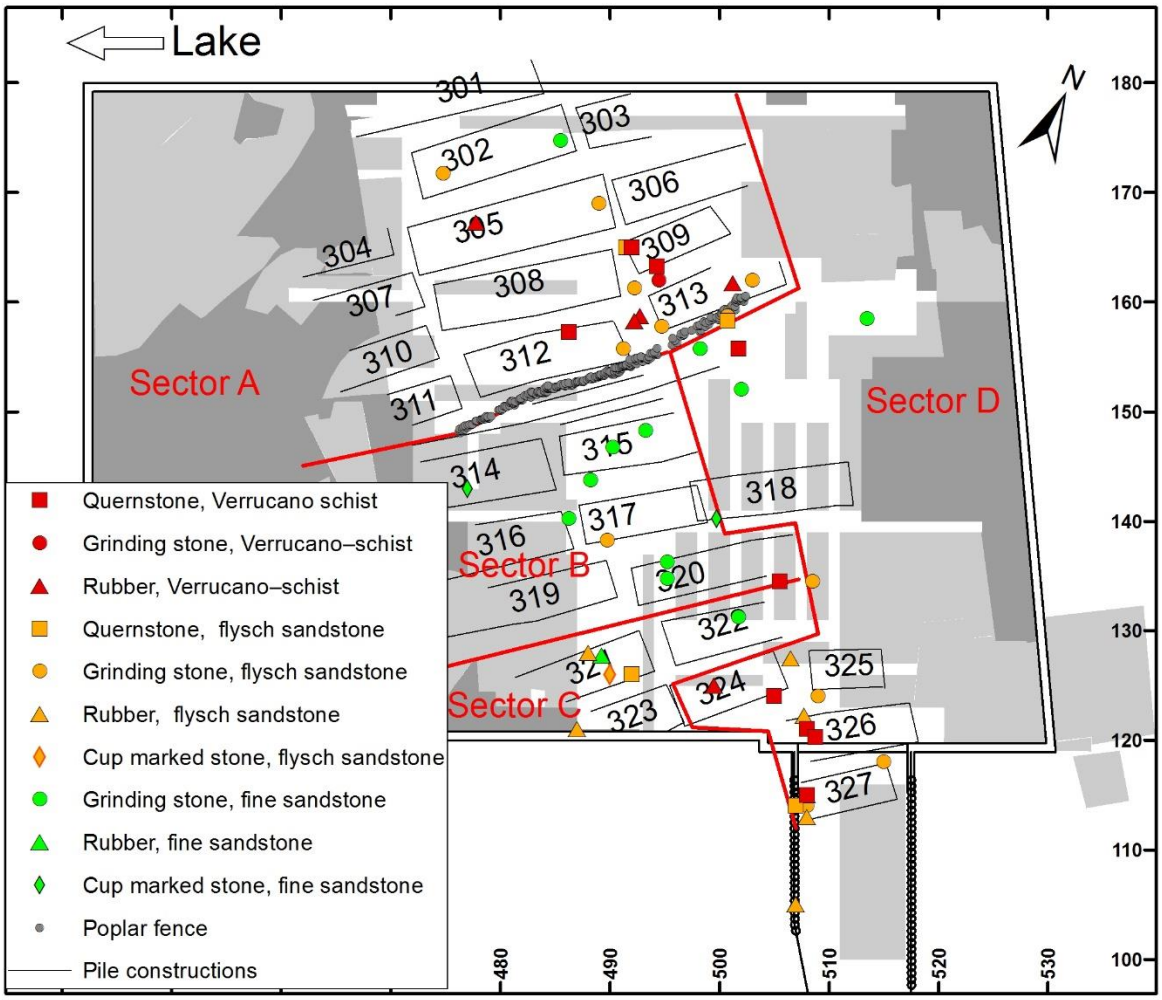


Figure S2. Map of woodworking tools and semi-finished adze handles in layer 13.

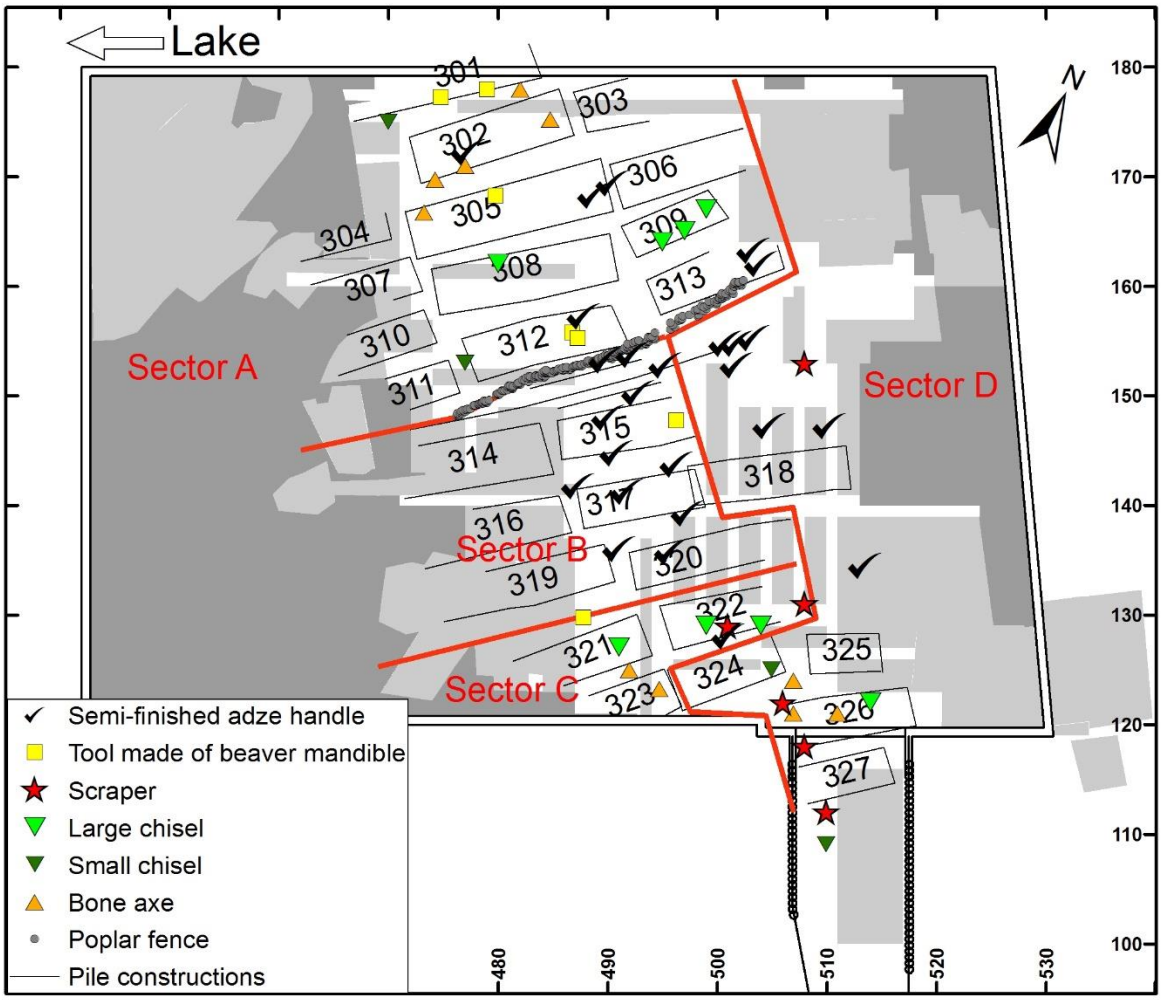


Figure S3. Map of linear building structures.

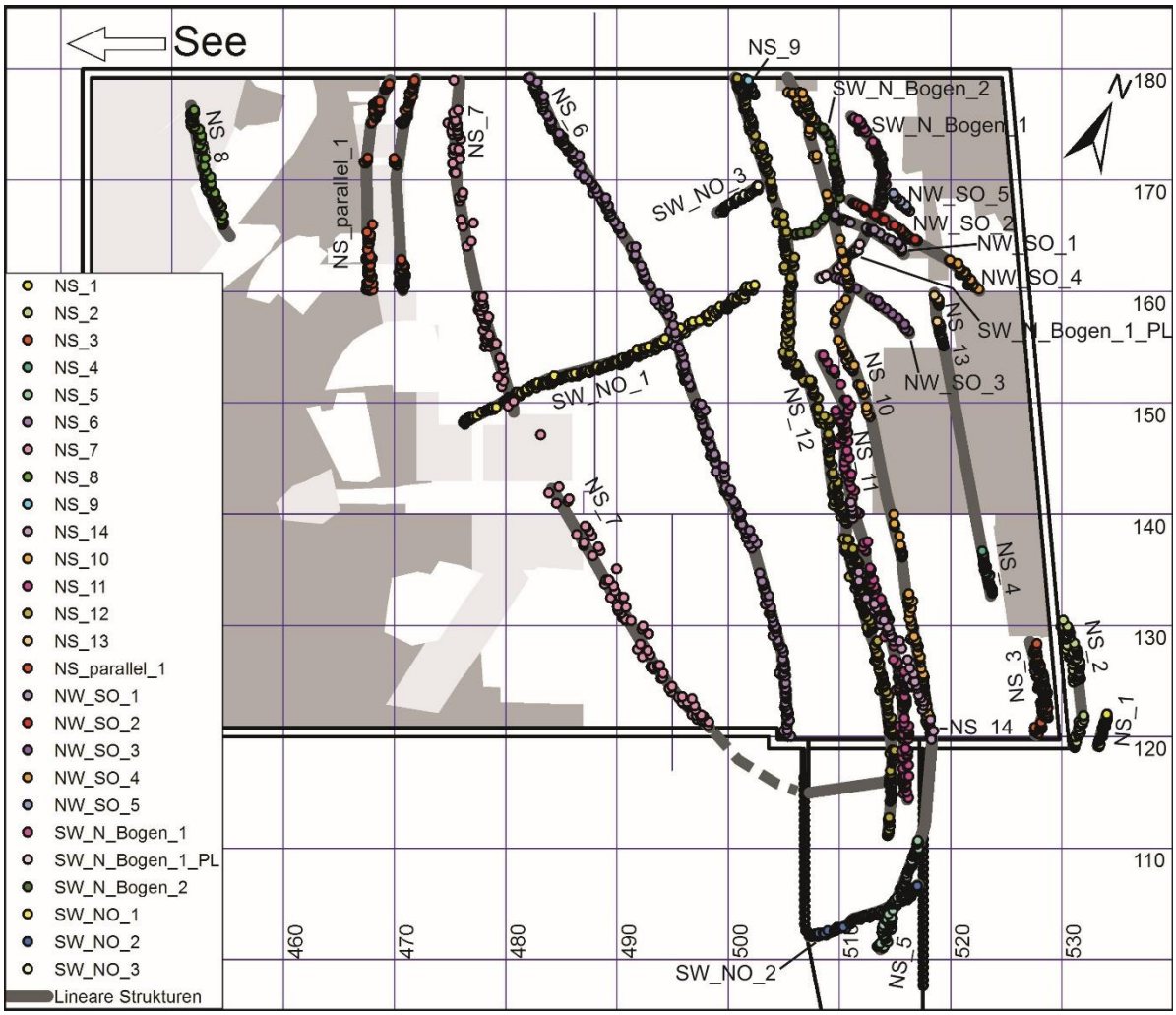
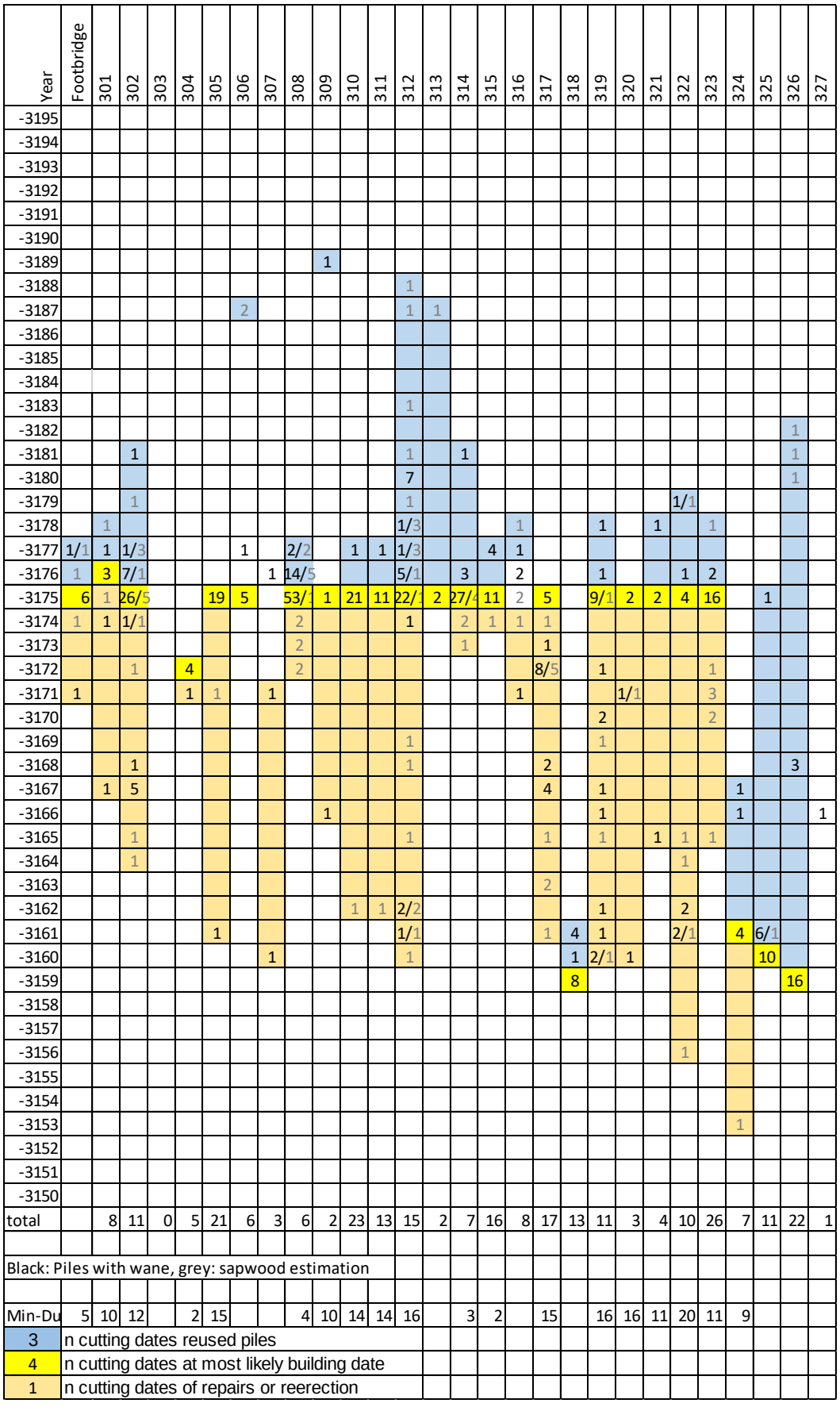


Figure S4. Cutting dates of piles per house from phase 3.



Year	Footbridge	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327
-3195																												
-3194																												
-3193																												
-3192																												
-3191																												
-3190																												
-3189										1																		
-3188													1															
-3187							2						1	1														
-3186																												
-3185																												
-3184																												
-3183													1															
-3182																											1	
-3181			1										1		1												1	
-3180													7														1	
-3179			1										1										1/1					
-3178		1											1/3				1			1		1		1				
-3177	1/1	1	1/3				1		2/2		1	1	1/3			4	1											
-3176	1	3	7/1					1	14/5				5/1		3		2			1			1	2				
-3175	6	1	26/5			19	5		53/1	1	21	11	22/1	2	27/4	11	2	5		9/1	2	2	4	16		1		
-3174	1	1	1/1						2				1		2	1	1	1										
-3173									2						1			1										
-3172			1		4				2									8/5		1				1				
-3171	1				1	1		1									1				1/1			3				
-3170																				2				2				
-3169													1							1								
-3168			1										1					2								3		
-3167		1	5															4		1					1			
-3166										1										1					1			1
-3165			1										1					1		1		1	1	1				
-3164			1																				1					
-3163																		2										
-3162											1	1	2/2							1			2					
-3161						1							1/1					1	4	1			2/1		4	6/1		
-3160								1					1						1	2/1	1					10		
-3159																			8								16	
-3158																												
-3157																												
-3156																							1					
-3155																												
-3154																												
-3153																									1			
-3152																												
-3151																												
-3150																												
total		8	11	0	5	21	6	3	6	2	23	13	15	2	7	16	8	17	13	11	3	4	10	26	7	11	22	1
Black: Piles with wane, grey: sapwood estimation																												
Min-Du	5	10	12		2	15			4	10	14	14	16		3	2		15		16	16	11	20	11	9			
3	n cutting dates reused piles																											
4	n cutting dates at most likely building date																											
1	n cutting dates of repairs or reerection																											

Figure S5. Cutting dates of piles and stratified timbers.

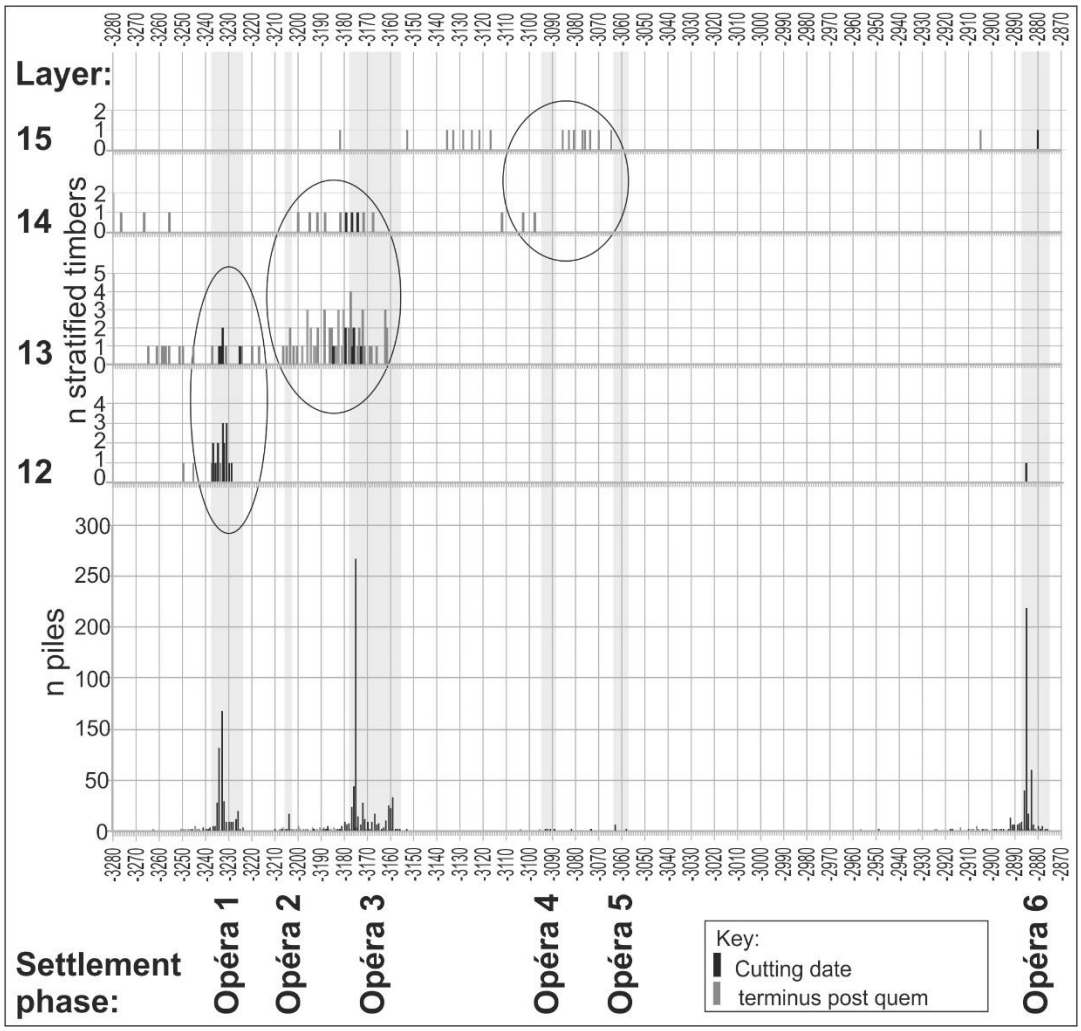
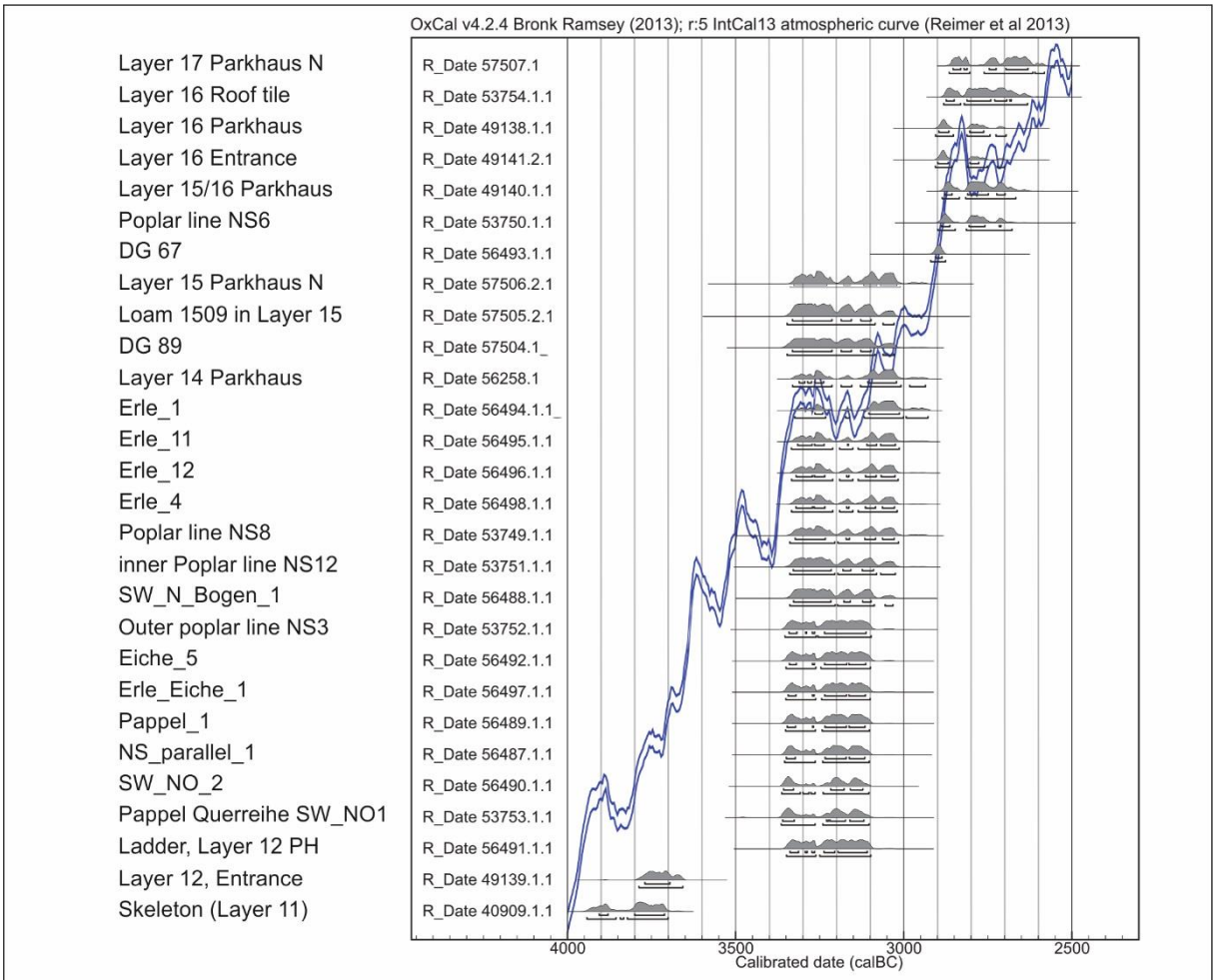


Figure S6. Radiocarbon dates from layers, dendrogroups and building structures.



ETH nr.	Sample	Comment	BP convent.	+-(y)	$\delta^{13}C$ (‰)	Structure / Object	1-Sigma range		2-Sigma range	
40909.1.1	Fknr 219.1	Bone	5005	35	-23.6	Skeleton (Layer 11)	-3906	-3712	-3943	-3702
49138.1.1	Fknr 10919	Hazelnut Snr 657	4223	30	-26.5	Schicht 16 Parkhaus	-2896	-2763	-2906	-2696
49139.1.1	Fknr 8572	Hazelnut Snr 116	4953	30	-27.0	Layer 12 Schillerstr.	-3771	-3696	-3788	-3658
49140.1.1	Fknr 10815	Hazelnut Snr 685	4180	29	-27.7	Layer 15 / 16 Parkhaus South	-2879	-2699	-2886	-2667
49141.2.1	Fknr 9426	Hazelnut Snr 122	4229	29	-24.7	Layer 16 Schillerstr.	-2899	-2777	-2907	-2701
53749.1.1	Hnr 27956	last 3 Rings	4457	33	-25.2	Lakeward Poplarline NS8	-3323	-3029	-3339	-3016
53750.1.1	Hnr 11784	last 4 Rings	4208	31	-25.7	Poplarline NS6	-2889	-2712	-2899	-2679
53751.1.1	Hnr 22630	aussen	4470	32	-28.2	inner Poplarline NS12	-3329	-3091	-3339	-3026
53752.1.1	Hnr 13249	last 4 Rings	4510	32	-26.7	outer Poplarline NS3	-3342	-3112	-3354	-3097
53753.1.1	Hnr 1747	aussen	4539	32	-24.8	Pappel Querreihe SW_NO1	-3361	-3119	-3365	-3104
53754.1.1	Hnr 18619	last 3 Rings	4166	32	-23.0	Rooftile Layer 16	-2875	-2681	-2882	-2633
56258.1.1	Fknr 11754	Twig 7 Rings, Snr 661	4443	29	-28.0	Layer 14 Parkhaus	-3320	-3020	-3330	-2930
56487.1.1	Hnr 26582	last 3 Rings	4521	27	-23.5	NS_parallel_1	-3350	-3117	-3355	-3103
56488.1.1	Hnr 7336	last 8 Rings	4480	27	-30.5	SW_N_Bogen_1	-3328	-3098	-3339	-3033
56489.1.1	Hnr 28088	last 12 Rings	4516	27	-23.9	Pappel_1	-3347	-3116	-3352	-3102
56490.1.1	Hnr 14331	last 15 Rings	4537	27	-22.9	SW_NO_2	-3358	-3122	-3364	-3104
56491.1.1	Hnr 12698	last 3 Rings	4506	27	-26.9	Ladder, Layer 12 Parkhaus	-3339	-3109	-3349	-3099
56492.1.1	Hnr 6255	last 3 Rings	4510	27	-24.0	Eiche_5	-3341	-3114	-3351	-3100
56493.1.1	Hnr 27000	last 5 Rings	4273	27	-25.8	DG67	-2907	-2887	-2920	-2876
56494.1.1	Hnr 25548	last 5 Rings	4431	27	-22.7	Erle_1	-3265	-3013	-3325	-2928
56495.1.1	Hnr 14687	last 3 Rings	4450	27	-25.1	Erle_11	-3316	-3026	-3335	-3014
56496.1.1	Hnr 4630	last 3 Rings	4453	27	-27.9	Erle_12	-3321	-3027	-3334	-3017
56497.1.1	Hnr 24437	last 3 Rings	4513	27	-25.6	Erle_Eiche1	-3344	-3115	-3351	-3101
56498.1.1	Hnr 20254	last 10 Rings	4456	27	-25.2	Erle 4	-3321	-3028	-3334	-3020
57504.1.1	Hnr 27748	last 4 Rings	4484	39	-40.1	DG89	-3330	-3096	-3346	-3028
57505.2.1	Hnr 19954	aussen	4479	32	-28.2	Lehmstelle 1509	-3330	-3090	-3340	-3020
57506.2.1	FkNr 8961	Hazelnut Snr 659	4454	31	-27.9	Layer 15_Parkhaus N	-3330	-3020	-3340	-3010
57507.1.1	FkNr 4885	Hazelnut Snr 286	4124	21	-32.3	Layer 17 Parkhaus N	-2853	-2630	-2864	-2580